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ABSTRACT

The intention of this guide is to consider the concepts, skills, facts, and attitudes of science which are taught in school; explore how content might be chosen; argue for a reduction in curriculum content; suggest major topics for science teaching; use examples to illustrate aspects of science content; and consider some of the implications of what is said. This guide, although written mainly for teachers, is an opportunity for science teachers and their colleagues to consider some important issues and to act upon some practical suggestions. Following an introduction, section one deals with what content is, whose content it is, a rationale for reducing content, an example on electricity, and other messages. Section two addresses the allocation of time, outcomes, relevance, competency, levels of attainment, criteria for selecting content, and aims versus criteria. Section three discusses skills, processes, and attitudes. Section four treats illustrations of electricity and relationships. Section five comments on resources and further study. An appendix presents a coordinated science program. Publications for further reading and references are included. (RT)

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SECONDARY SCIENCE CURRICULUM REVIEW

SSCR

BETTER SCIENCE:
Choosing content

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Curriculum Guides

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SECONDARY SCIENCE CURRICULUM REVIEW

SSCR

BETTER SCIENCE:

Choosing content

Curriculum Guide 2

Compiled by Mike Watts and Mick Michell

Heinemann Educational Books/Association for Science Education
for the School Curriculum Development Committee

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Foreword

This is the second in a collection of twelve Curriculum Guides from the Secondary Science Curriculum Review, published jointly by Heinemann Educational Books and the Association for Science Education.

A *Directory of Resources* and a book, *Better Science: Making it happen*, which tries to set the Review's recommendations in the context of the whole school, will appear at the same time as the Guides. These will, when taken with earlier and forthcoming SSCR publications, including those from local groups, constitute the recommendations which the Review is making towards a broad and balanced science education for all the young people in our schools. The series title, 'Better Science' is thus both apposite and self-explanatory. It is hoped that the current phase of the Review (1986–89) will achieve successful implementation of the recommendations.

But what is the status of these new publications apart from reflecting the formal approval and support of our major sponsors, the School Curriculum Development Committee and the Association for Science Education? From what sources have the recommendations within them emanated? Those readers unfamiliar with the history of the SSCR will find it explained within the Guides; but most will be aware that it set out as a project which tried to involve fully the practising teacher in the development of solutions to the problem of science for all. Thus, although the Guides have been compiled principally by the Central Team of the Review, they draw on the work of thousands of teachers in working groups over the past four years. Although the work of many of the groups is referred to in the Guides, it is not possible to refer to it all. In the *Directory of Resources* readers will find details of what many of these groups have produced. The writing of these Guides, however, would not have been possible without the groups' existence and the Review Central Team hopes that the content of the Guides truly reflects their work. Thus the pronoun 'we', used within them, often reflects the view, gleaned over five years of consultation, of the practising teachers involved with the Review. On other occasions it can represent the views of the SSCR as constituted by the Central Team and Steering Committee and it is hoped that particular usage will be apparent from the context.

Jeff Kirkham
Mick Michell
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Dick West
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Introduction

Our intention in this booklet is to discuss the content of school science 11–16. More specifically it is:

- to consider what content is;
- to explore how the content of school science might be chosen;
- to argue for a reduction in traditional curriculum content;
- to suggest major topics for science;
- to illustrate aspects of science content through examples;
- to consider some of the implications of what we say.

This guide is written principally for teachers of science but it is hoped that it will be of interest to their colleagues in other departments and to those in education outside schools. It is an invitation to science teachers and their colleagues to consider some key issues and to act upon some practical suggestions. It is intended, too, for both teachers of science in primary schools and sixth-form specialists. It may also appeal to those with a broad interest in curricular matters. Whilst it is not written with all their particular problems in mind, we hope it will provide some interesting insights and information about what we are suggesting for our secondary school colleagues.

All the topics and essential features that go into making up a school subject area are frequently referred to, for brevity, as its 'content'. In this booklet the content of school science means the substance – the facts, concepts, skills and attitudes of science taught in school to 11- to 16-year-olds. Numerous reasons have been given to argue that the content of school science is too great and that it needs to be reduced. This resource booklet is intended to examine these reasons and to make suggestions for the future. The problem of reducing content is a thorny one. Much school science has simply grown like 'Topsy' to fill any and all available space without too much collective forethought and planning. To change common practice, to throw out time-honoured and familiar parts of science and to introduce new and unfamiliar aspects, is not a straightforward task. Our central reason for wanting to reduce the traditional – factual – content of school science is to create more time to enable a change in emphasis in science education. The new emphasis would be on:

- more thorough learning across a range of sciences;
- improved pupil performance and competence in science;
- development of important processes, skills, concepts and attitudes;
- exploration of approaches to teaching and learning;
- technological applications and problem-solving activities;
- consideration of the social, moral, ethical and economic implications of science.

There are two ways to revise the content of school science:

1 to review the content of the major courses and examination syllabuses currently available and combine and trim these as required;
2 to begin with a 'blank sheet of paper' and write in the content of science education from nothing.

We have chosen from the second route. We have preferred to argue for the inclusion of content rather than to suggest what might be excluded from other lists. At the same time we recognise the clear need to reduce what has become the traditional teaching load in the sciences. Thus we have aimed at a reduction of the current content 'information base'.

There is wide variation in the way the word 'content' is used and in what is intended by it. In this booklet we have explained as far as possible what we mean.

Our remit in this booklet stems from the intended outcomes of the Secondary Science Curriculum Review. In the document *Science Education 11–16: Proposals for action and consultation* (**0.1**) the Review stated that its intention was to publish a report detailing.

> *an appropriate, coherent and parsimonious selection of content drawn from biology, chemistry and physics suitably augmented by the inclusion of subject matter from other areas of science.*

SECTION ONE

Setting the scene

If we are concerned with reducing the content of science education, we might ask:

- What is content?
- Whose content is it?
- Why reduce it?

What is content?

It might seem self-evident to everyone in schools just what the word 'content' means. In fact, the term is understood very differently by different people.

Throughout this booklet we intend that the content of school science should be comprised of:

- facts;
- concepts;
- theories, principles, laws;
- skills;
- processes;
- attitudes.

You will recognise what we mean by most of these, but some examples might help. We include, for instance:

- facts – like nomenclature, numerical constants and units;
- concepts – such as energy, osmosis, reactivity and time;
- theories – of evolution, tectonic plates, kinetic theory; principles of conservation (of energy, or mass); laws like Ohm's or Kirchoff's;
- skills – such as numeracy, graphicacy, manipulative skills, listening and discussing;
- processes – at two levels – *in* science, and *of* science. Processes *in* science include respiration, electrolysis and communication; the processes *of* science might include observation, hypothesis testing and evaluation of evidence;
- attitudes – such as curiosity, open-mindedness and concern for living things.

That is, we are using the term 'content' to cover all the aspects of science that we think are part of school science. This is slightly unusual. Some writers prefer to keep 'content' to mean knowledge of facts and principles in science in order to contrast it with the processes of science, or particular contexts in which they might be applied. But it seems to us quite false to separate content in this sense from processes, or these from skills and attitudes.

School science is not science. It may resemble science in many ways but has, as Smolicz and Nunan (**1.1**) have argued, little in common with the activities in which scientists engage in the laboratory. The content of school science is what teachers, employers, examiners and curriculum developers want it to be. The content – what fills up the lessons – should not be simply the facts and principles of science, but needs other components as well. These other components are applicable throughout the curriculum and fulfil many educational demands. The content of school science is therefore the vehicle for teaching the concepts, skills, processes and attitudes we think are important.

Whose content is it?

This is not a usual question to ask. We see the answers, though, as important. No-one has copyright on school science.

There is a sense, though, in which few youngsters can say that the science they do at school belongs to them – even after five (or more) years of doing it. It is seldom relevant to their needs or much use (beyond passing exams) for life outside or after school. As the DES policy statement, *Science Education 5–16* (**1.2**) says:

> *Although there are some impressive exceptions, too much of the time spent learning science by too many pupils consists of the accumulation of facts and principles which have little perceived, or indeed actual, relevance to their daily lives as young people or as adults. Few science courses draw on the experiences that pupils can bring from their everyday lives. Most experiments and many illustrative examples are laboratory based and divorced from the present-day world. Too many examples of the technological applications of science included in science courses and examinations reflect past developments rather than current ones.*

It is the kind of view that many youngsters themselves make known (see, for example, *'Science is Like a Spider's Web'?* (**1.3**)). A number of good reasons could be put forward to suggest why school science is seen like this. One reason might be that the science we teach is not particularly 'user friendly' and, were we able to start again, we might teach more effectively if we chose the content of science more carefully.

A recent publication on teacher appraisal (**1.4**) suggests that there is broad agreement as to the effect that teachers should have:

> *. . . pupils should be learning subject matter which consists of information, skills and attitudes;*

at the same time they should be helped to recognise their increasing competence, feel better about themselves as individuals, become better, more cooperative members of the community, develop more responsibility, increase problem-solving ability, prepare for the world of work and develop independence.

We think that the notion of youngsters gaining – and recognising that they have gained – increasing competence is important. Competence is an issue we return to later in our discussion. In short, we take it to mean that youngsters are able to make skills, knowledge and understanding their own.

Ownership in this sense describes what young people take with them at the end of a series of courses in science subjects over five years. We would want them to be able to redeploy their skills, knowledge and understanding in other contexts outside school – whether it is in or out of work, or for further study. We cannot in this short discussion document detail every single item of science content we feel youngsters might ideally own. It would be improper, too, since some of the choice must lie with them. Nevertheless, we do try to develop some ideas and build upon the early work of the Secondary Science Curriculum Review as set out, for example, in *Towards the Specification of Minimum Entitlement: Brenda and friends* (**1.5**).

Some of the answers to our question 'Who owns science?' might be that school science is the domain of examination boards, textbooks or university departments. There is a sense in which it belongs to all such bodies and yet to none. All have a legitimate say in the content and development of school science and we need to pay attention to their requirements. No one organisation has a veto on what should be studied and school science has to meet a wide range of (often competing) demands. In this booklet we have noted the responses of many organisations to the SSCR's first consultative document (detailed in *A report on responses to the consultative process* (**1.6**)). Three major requirements are apparent.

1 a minimum level of scientific literacy for all youngsters;
2 provision for further study in science;
3 the drawing of more girls into science and technology.

These concerns are reflected in the aims of the Secondary Science Curriculum Review (**0.1**) which include specific aims for science itself, as well as some general educational aims that can be achieved through the teaching of science.

The important aims here are those that look to provide 'adequate opportunities for all students:

1 to study the key concepts and principles of science as a way of looking at the world;
2 to study those aspects of science that are essential to an understanding of oneself, and of one's personal well-being;
3 to study the key areas of science and technology that relate to the world of work and leisure so that they are better able to participate in a democratic society;
4 to study key concepts that are essential to an understanding of the part science and technology play in a post-industrial and technological society;
5 to discuss, reflect upon and evaluate their own personal understanding of key scientific concepts, theories and generalisations;
6 to explore topics and themes which exemplify the limitations of scientific knowledge as an explanation of the human condition.'

Box 1 *Aims of science education*

To achieve aims like those in Box 1, it is possible to pick up science at any one of a number of starting points. Rather than seeing the content of science as a necessary hierarchy, as some curriculum materials suggest, we prefer to think of the facts, concepts, principles and theories as linked together as a net. It is possible to pick the net up at many specific points or, indeed, to put it down for a while and then follow the networks along to reach other interesting and informative points. The routes through the content of science are numerous and varied and depend upon a wide range of factors.

For example, not all science content is equally learnable. We know from research and experience that some parts of science are more difficult to learn than others. Concepts like energy, force, heat, electricity, the mole and evolution are all difficult and complex. These are also, paradoxically, considered to be some of the fundamental or basic concepts in science. If such concepts are so difficult then there are three possibilities:

- They should be dropped from the school curriculum altogether.
- They should be given more time and resources to ensure that youngsters have the opportunities to come fully to grips with them.
- Teaching should be restricted to levels we know can be understood by most (all) pupils.

The choice of alternative will depend upon the importance we attach to the concepts. The problem we are then left with is how to justify the importance of the concepts we choose to include. We discuss this in the *Criteria for selecting content* in Section 2. We also set out our content list itself in

Section 3 of this guide. In it we follow each of the possibilities above to some extent. We have not included some of the more unlearnable parts of science; we advocate much more time for tackling difficult ideas and we try to give some indication of the level of treatment we think appropriate. It is important to remember that it is a list and not a syllabus. We deliberately present it in alphabetical order so as not to imply a hierarchy or teaching order. We have found it difficult to decide how detailed the list should be. It would be tediously overbearing, and perhaps very prescriptive, to treat each of our major topic areas in very fine detail. However, it is also unhelpful to introduce descriptors at a level that leaves them subtle and vague. We have chosen to detail our content in two ways – first by describing two of our topics ('Relationships' and 'Electricity') in finer detail, and secondly by drawing on the work of groups in the Review who have developed similar approaches.

Why reduce content?

At the present time a number of organisations are looking closely at the content of school science. The demand to reduce the content of the secondary science curriculum has been articulated by various organisations, including:

- The Association for Science Education (ASE) (1981) (**1.7**);
- Her Majesty's Inspectorate (1982) (**1.8**);
- The Department of Education and Science and The Welsh Office (1985) (**1.2**);
- The Royal Society (1982) (**1.9**).

Moreover, in discussion and consultation teachers commonly quote content overload as a major constraint upon curriculum development. We can group problems with the current content of school science in three ways:

1 problems of too much;
2 problems of too little;
3 problems of undelivered messages.

Problems of too much

We can do no better here than quote from the DES policy statement, *Science Education 5–16*, para 78 (**1.2**):

> *. . . if science is to be taught to convey understanding and confidence in the use of the knowledge gained, as well as the necessary and central skills, both practical and intellectual, then the factual and theoretical content of many existing courses will need to be sharply pruned. This task can, and should, be carried out without reducing the intellectual demands made on pupils or the rigour with which science is taught.*

We detect widespread dissatisfaction with the overcrowded syllabuses of many school science courses. There is much that is regarded as clutter which teachers resent having to teach and which few pupils enjoy having to learn. Out-of-date examples of important phenomena, rote learning of nomenclature or formulae, and so-called 'relevance' tacked on to courses, are merely the more obvious manifestations of this dissatisfaction. Few teachers find they can combine an attempt at thorough competence by all their pupils in a particular area with completion of all the areas required. How many play the 'past papers game' in the last term before examinations – of trying to gamble that what came up last year will not reappear this year, and so can safely be dropped because there simply is not time to 'cover' everything?

Lastly, broad and balanced science needs to be offered to youngsters in the time allocation supported by the SSCR, the DES, the ASE and the Royal Society. This clearly means pruning the conventional content offered in separate subject courses.

Problems of too little

Few conventional school science courses are complete. Only a small proportion of youngsters gain access to the earth sciences, to astronomy, to microelectronics and to many topics in weather, conservation and technology. These subjects deserve to be considered for inclusion in a science syllabus available to all students. Thus the rough and ready 'three into two' calculation (often used when questions of content are being considered) just will not do. Cutting conventional content by at least half, to allow for the inclusion of some of the above areas, would seem to be needed.

Problems of undelivered messages

The work of the Assessment of Performance Unit and latterly of the Children's Learning in Science Project (CLISP) must now be considered. Results from both of these important initiatives are difficult to summarise in the space available here. A more complete picture can be obtained from their publications (Refs **1.10** and **1.11**). It might help to consider an example.

Electricity: an example

Electricity is a key concept in science and would surely find its way into most school science curricula. The APU survey at age 15 (**1.12**) says of all the pupils surveyed that, in terms of handling simple circuits:

- The majority of pupils are familiar with the symbols for individual electrical components – particularly in a practical situation.
- About two-thirds can connect a circuit to match a photograph.
- But only a fifth or fewer can either draw a circuit diagram or set up a circuit to match such a diagram.
- Many pupils have difficulty with reading an ammeter, only 11 per cent getting the correct value. With the less complicated scale on the voltmeter, 61 per cent were correct.
- Only one in ten pupils successfully connected both an ammeter and a voltmeter into a circuit. Many connected the voltmeter in series.

Parallel circuits give the most problems. In terms of understanding basic ideas:

- A quarter of pupils use the idea of constant current in a familiar simple circuit of two bulbs.
- Less than 10 per cent do so in the less familiar case of five bulbs in series.
- Some 10 per cent think that positive and negative currents flow from the ends of the batteries and 'clash' in the bulb.
- As many as 50 per cent give responses based on some sharing or 'using up' of 'something' – often the something is described in terms connected with electricity such as power, energy, and electricity itself, but used with an imprecise or 'everyday' meaning.

Moreover, girls perform significantly less well than boys on the tests.

One unmistakeable summary of the findings of the APU is that either we are attempting to teach children concepts which they are not ready to grasp, that the match between courses and their recipients is problematic, or that we are teaching science and youngsters poorly! The truth is probably somewhere between these extremes, but one message is clear. We must allow greater time for the content which we do include to be appreciated.

CLISP, by concentrating on the conceptualisation of the 'big ideas' of science, has performed a valuable service. The project's current phase is concerned with developing materials for the classroom which take into account youngsters' prior knowledge. These promise to be of considerable value for the hard-pressed classroom teacher.

Other messages

There are other messages about science that also need to be communicated. For example, science is not all dour logic and calculation. It involves and affects people, it is creative and it has a strong sense of culture and history. Neither is it all-powerful (a popular myth) and it has its limitations as a way of looking at the world. In the past, science has depended upon both team efforts and individual enterprise, sometimes upon personal meanings and often upon social understandings and conventions. We would want to make time, then, within science lessons to explore many facets of science itself.

We now return to the question of how to reduce content. The metaphor of pruning content is unfortunate in some ways. For example, it can give the impression that science education carries an amount of dead wood which simply needs to be cut away to make everything fine again. It also carries the connotation that what is needed is a trimming exercise and not a fundamental reappraisal. We mentioned in the introduction that we have chosen quite deliberately, and in contrast to some other syllabus reduction exercises, to specify the content of science and to argue for the inclusion of topics rather than to take common syllabuses and to exclude sections. We have attempted to describe the content of school science in terms of learning outcomes.

There are always problems in simply producing a list of items to be covered, principles to be applied or concepts to be grasped. There are real problems, too, in attempting to specify what learning should take place in any teaching and learning situation. We have chosen the first route and shall develop our notion of competence in school science, and some of the advantages that this brings, a little later. Before that, we take a slightly different way of specifying content.

SECTION TWO

Time for competence

In this section we consider the recommended time allocation for science in the curriculum and what we mean by competence.

Time allocation

One approach to discussing content is to start with the arithmetic of the time available. The school year is nominally 190 days, giving 950 school days over the period of interest to us – the five years between 11 and 16. A school day is about five hours long, giving a youngster some 4750 hours of schooling in those five years. The most recent recommendations (for example, from the DES and the SSCR **1.2**, **0.1**) of time allocated for science are 10 per cent in years 1 and 2, 15 per cent in year 3 and 20 per cent in years 4 and 5. This is an average of 15 per cent over the five years, amounting to about 700 hours of science. Depending upon timetable arrangements, this could be something like 700 hourly lessons or 500 double periods.

> Put another way, it might be:
> 2.5 hours per week in years 1 and 2;
> 3.5 hours per week in year three;
> 5 hours per week in years 4 and 5.

Box 2 *Hours of science per week*

These recommended time allocations have important implications. They are guidelines which refer to science for all students. At the moment the allocations of time for science vary dramatically from one school to another. Whilst it is not uncommon for youngsters in years 1 and 2 to spend 10 per cent of their time on science, the variation in years 4 and 5 is considerable. For students taking seven or eight O-level subjects, the combination of biology, chemistry and physics may represent some 30 or even 40 per cent of curriculum time. At the other extreme there are many youngsters who do no science at all in years 4 and 5. One consequence, therefore, is that the recommended figures represent a huge increase in science for some, and a decrease for others. Twenty per cent of curriculum time in years 4 and 5 means that all students will have the equivalent of one day a week of science.

Other questions are raised by this sort of calculation. For example:

- Is it possible to decide the proportion of time that should be devoted to each of the elements of content that we have suggested? How much time should be spent teaching skills, or practical work, for instance?
- How much time should be given to the teaching of particular topics like energy, electricity or reactivity?

There is no one answer to questions like these. The way time is spent within a science course reflects the priorities of individual schools and departments. It reflects, too, the level of understanding required of pupils. However, in our view it is important that thought should be given to establishing such priorities within each school. We specify our list of content to cover the five years from 11 to 16 – it is not a list intended simply for examination purposes in years 4 and 5.

Competence: a concern for outcomes

Recent research in science education (as documented, for example, by the SSCR and CLISP (**2.1**, **1.11**)) has illustrated that the content and the immediate context into which it is placed have a major influence both on what is learnt and on how it is learnt.

The problems youngsters experience in learning about heat, for instance, are different from problems in learning about force and motion, or plant nutrition. Moreover, learning about heat in terms of standard laboratory experiments on conduction presents different problems from the ones met in learning about heat in terms of common everyday experiences – in explaining why, for example, the metal handlebars on a bicycle feel cold. It is notoriously difficult for youngsters to transfer their learning from one context to another, to apply concepts in science. The greater the difference in the context, the greater are the difficulties in effective transfer. The APU (**1.12**) argues that:

- The performance of all pupils is low when they are asked to apply scientific concepts.
- Performance is particularly low when they are asked to apply science concepts that they have been taught in some other science context.

The members of the APU argue that the reasons for failure are complex, but that it is important to create time within the science curriculum to allow youngsters to become familiar with the concepts they do meet, and to use them in a variety of situations.

The relative failure of pupils to apply concepts must be cause for concern. The ability to use and apply understanding is clearly important –

youngsters should be able to apply concepts and to use them in different contexts.

These findings reflect on current approaches towards teaching and learning. Lecturing a group may not be the best way of teaching about attitudes, for instance; worksheets may not be the best way to develop laboratory skills. In this booklet we view teaching and learning in science in terms of enabling competence. That is, we expect science teachers to create varied situations which enable pupils to become competent in science. It is a position similar to that advocated by the Association for Science Education (1981) (**1.7**) when it says that

> *the key to successful teaching . . . rests in the ability to produce an effective match between teacher, pupil and task . . .*

We need to say what we mean by competence. Here, we use the word competence to mean that a person is able to use knowledge, understanding, process and practical skills and, as a result, will act effectively to achieve a purpose both within an immediate context and across appropriate contexts.

Relevance and usefulness

Science must be seen to be relevant and applicable both within the context of school life and outside in the world of work and leisure. That is, youngsters should be able to use their understandings of science within an immediate context, and to transfer that understanding and use it appropriately in some other context.

Flexibility and adaptability are among the most valuable qualities a youngster can attain. At the heart of these qualities lies the notion of capability and competence. A youngster with only a narrow understanding of principles and practice within science is increasingly less attractive within the world of work and learning (*Isn't That Rather Commercial?* (**2.2**)).

It might help to return to the example of electricity and the APU report (**1.12**). The authors question whether enough time is spent on circuit diagrams and simple circuits, and in helping youngsters to transfer that understanding to real situations. They say:

> *Careful and painstaking work with practical circuits could be rendered useless if subsequent work is based largely on circuit diagrams whose connection with the reality of practical experience is not well understood . . . is the gap between knowing perhaps very little about circuits to using a circuit board too large for the majority of pupils? Could it be that a circuit board is not much more than a mechanical puzzle? Whether this is the case or not there is surely a need for an extended period of introductory work on circuits with wire and simple bulb and battery holders where the function of the parts of the circuit is more evident.*

Being competent

For young people, as well as concerned adults, competence in science contributes to a greater confidence – a confidence that comes from coping with different demands within the subject area. As Hayes *et al.* (**2.3**) suggest, competence enables young people themselves to own the understandings and skills they have developed. Performing a task effectively – competently – gives the self-confidence which comes from succeeding in a wider context. It means using process skills to marshall knowledge and understanding, and practical skills to achieve an end result. It means being able to transfer these skills from one context to another. Competence can be arrived at, however basic the level of knowledge, skill and understanding. It means achievement under pressure, and sometimes in circumstances which are unfamiliar or which contain unforeseen difficulties.

We would agree that the three essential components of competence are:

- ownership;
- transfer;
- decision making.

In *Towards the Specification of Minimum Entitlement* (**1.5**) the SSCR discussed the provision of science education in terms of what the average student should have gained by the end of compulsory schooling. This was depicted by a series of fictional narratives which illustrated what students might take away from school at that stage. Ownership is important because it indicates that the learning taking place is intelligible, credible, fruitful and relevant to the youngsters concerned.

The type and extent of the knowledge, skills and attitudes owned are also important. A youngster who is taught only one science specialism, for example, has few opportunities to become competent in appreciating or tackling a wider scientific problem. One science subject in isolation cannot provide a sufficiently broad foundation of knowledge to allow pupils to own competencies which can easily be applied in other contexts.

Ownership, too, implies the ability for decision making. A balanced science content, a broadly based topic area, allows greater freedom of choice in decision making, which in turn increases the opportunity to own and redeploy knowledge and skills.

Progression and levels of attainment

We are not suggesting that there is only one level of understanding in science – nor in any other subject area, for that matter. The act of understanding does not usually consist of a switch from the state of non-understanding to that of complete comprehension as a result of a single action or experience. This may sometimes happen for some people, but on most occasions understanding is a slow process of assimilating ideas and of testing out parts and gaining confidence in their form and function. By this process understanding grows over a period of time. Only some of the process of understanding is content dependent. It also depends upon the processes, skills and attitudes that make up the cognitive and affective aspects of the individual's personality.

An interesting example of how levels of attainment in school science can be specified is to be found in the work of the SSCR Suffolk group in *The Coordinated Science Project* **(2.4)**.

Criteria for selecting content

In designing school science courses and in selecting the content for them we are faced with the difficult problem of deciding what to put into a particular course – and what to leave out. This begs the questions:

- Why are particular topics included within science courses?
- Are there some aspects of science that must be present in all courses, or should the content of school science be open and flexible to respond to different needs?

These questions have been discussed extensively at different levels over many years. Obviously, there is no single criterion for deciding the content of school science. Different teachers will use different criteria. Also, there are many people who have a legitimate stake in choosing the content of school science courses – subject associations, parents, teachers, employers, industrial organisations and youngsters themselves – and different groups of people will generate different content lists. For example, a parent's list might be different from an industrialist's, and a science inspector's from an educational psychologist's.

Naturally such responses raise many further questions and we shall try to answer some of them in the following pages. Many schools and teachers already make choices about content, and will continue to do so. It is also worth considering some other lists of criteria – if only to illustrate the variety of lists that can be generated.

The following quotations illustrate some of the criteria which are given. They are taken from responses to an early pilot paper on the content of school science:

1 The content should contain elements which assist in developing more general educational factors such as numeracy and literacy.
2 Content should reflect the structure of the discipline, science as cultural heritage – all the most important theories and ideas should be included.
3 The list of content should 'hang together' and make sense.
4 Is any particular item an indispensible component of any five-year programme of science studies?
5 An indispensibility criterion could be written: does learning about, and acquiring an understanding of this topic
   – make possible an appreciation of science as a way of looking at the world;
   – contribute to a fuller understanding of oneself, and of one's personal well-being;
   – deepen understanding of the role(s) of science and technology in today's society;
   – enable the learner to participate more constructively in her/his society?
6 Content must be taught in a practical way, which implies a maximum class size of 18 students.
7 Is the content a suitable vehicle for young people to use in forming and testing their own ideas and in appreciating the ideas and tests carried out by scientists in the past?
8 Content should be capable of being made appealing to both male and female students.
9 Any list of content ought to make the value position upon which it is based very clear.
10 Will the inclusion of content serve to underpin and extend studied concepts or merely be clutter?
11 Is gender bias excluded as far as possible?
12 Does the content avoid race bias?
13 Does content illustrate an appreciation of the social, economic and environmental implications of scientific/technological development and progress?
14 Does the content take any account of the content of other subject areas and by whom they should be taught?
15 Is all content to be taught to all pupils?

Box 3 *Responses to a pilot paper*

Some other lists of criteria

The following list of criteria for the inclusion of concepts, skills, processes and attitudes is based on work by John Darke, Dorset Science Adviser.

The following criteria should apply to selected content:

1 It should concern survival of the human race.
2 It should concern survival of the individual in a rapidly changing world.
3 The significance should be self-evident.
4 The effective use of leisure should be a main consideration.
5 The ability to make choices should be developed and the knowledge on what grounds choices are made.
6 It should involve education for environmental health.
7 It should involve education for personal health.
8 It should develop the skill of appraising someone else's evidence (media presentations, etc.).
9 It should develop the skill of obtaining and using one's own evidence.

Box 4 *Rules of selection*

Our next example is taken from the work of Cambridgeshire groups within the SSCR (unpublished). In preparation for an SSCR conference in Peterborough in July 1985, they wrote in the conference brief that:

> *The question of content is a minefield. One person's clutter is another person's gem. Perhaps it is more important that as teachers we are satisfied with our reasons for choosing items of content and also we can then justify our choices to others, e.g. the children.*

Then followed suggested criteria for selecting and introducing content (Box 5).

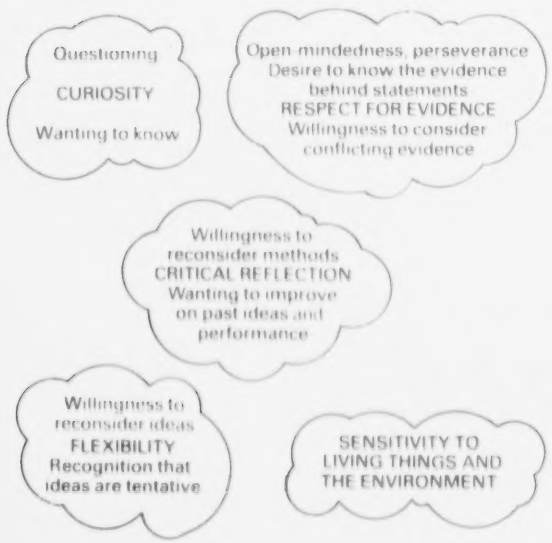


Fig. 1 *Scientific attitudes*

The content should perform the following functions:

1 It introduces children to current scientific theories.
2 It gives children useful (personal and vocational) knowledge.
3 It introduces children to knowledge that is the foundation for further studies in science.
4 It encourages attitudes of enthusiasm and curiosity.
5 It demonstrates how science can explain the natural and synthetic environment.

Educational criteria The content should have the following features:

1 Children find it significant.
2 It is appropriate to the children's level of development.
3 It can be taught in a variety of ways.
4 Science teachers have been or can be trained to have knowledge of it.
5 It maintains a balance between the major areas of science – biology, chemistry and physics – and introduces children to more neglected areas, e.g. geology, meteorology and psychology.

Organisational criteria The content should have the following advantages:

1 The necessary resources such as books, worksheets and apparatus are easily available.
2 It can be organised within the available school environment in terms of labs, rooms, technicians and time.
3 It can be integrated or coordinated into whole curriculum structures.
4 It is introduced so as to allow flexibility within a science department's structure. (Does all content have to be introduced in a hierarchical fashion, for example?)

Cultural criteria The content should fulfil the following requirements:

1 It introduces alternative scientific theories (contemporary and historical) in a way that doesn't support notions of cultural superiority.
2 It appeals to both boys and girls and doesn't put ethnic minorities at a disadvantage.
3 It recognises scientific knowledge as a cultural determinant relevant to societal issues and significant in children's development.
4 It allows the science curriculum to interact with other curriculum areas such as health education and technological education, as well as other subjects like maths, history and home economics.

Box 5 *'Cambridge' criteria for scientific content in schools*

Our criteria

As a first step to setting out our criteria, we suggest four points:

1 Our criteria come from a range of sources, but the strongest influence has come from the aims for science education expressed in (**0.1**).
2 Our criteria are written from our own experience and the experience of our colleagues in the Review network who have shared ideas with us.
3 Since no one criterion is all-important, the content to be included should satisfy as many criteria as possible – it does not have to satisfy all of them.
4 Our criteria are numbered in order of importance/significance.

We would propose the following criteria for the choice of content in school science:

1 The content included should maximise the possibility of teaching the processes, skills and attitudes important to science, and increase the competence and capability of pupils.
2 It must be able to be taught to, and owned by, all pupils.
3 The content should have some relevance and applicability. It must need to be known and be transferable to a range of contexts during and after school.
4 The content must appeal to both male and female students, and to students of differing cultures.
5 Science content should be consistent with a broad and balanced science curriculum.
6 The necessary teaching strategies and resources must exist to teach it.
7 It must provide a basis for further study.
8 It must take into account local circumstances.

Box 6 Our criteria

These criteria are not simple. For example, we have to be clear what processes, skills and attitudes we are trying to develop and how these might be achieved. (This is discussed in more detail in the Curriculum Guide, **Better Science: Learning how to teach it**.) We must also be clear about an expression like 'needs to be known' in criterion 3. What is it in everyday life that one 'needs to know'? It is worth, then, teasing out some of the issues contained in our criteria.

Aims versus criteria

Our criteria do not come directly from the aims for science education we mentioned earlier. They have been drawn from many comments and responses to earlier papers. By linking the aims and the criteria, however, we can explore both further. Aims are the broad purposes we intend of science education; criteria are limiting principles which help shape them. For instance, the first aim we mention in Box 1 is to provide opportunities for youngsters to study the key concepts and principles of science as a way of looking at the world. Our first criterion (Box 6 is that those concepts should be chosen that will maximise the teaching of processes, skills and attitudes. We can cross-reference each of the aims with the criteria in this way to structure our choice of content. If we set the six aims we noted earlier against our eight criteria, the matrix opposite might result (Fig. 2). The matrix is a combination of aims and criteria. Cell A, for instance, denotes that in science education we must include concepts which are essential to an understanding of science and technology, which must also be part of a broad and balanced curriculum.

In Section 3 we relate our list of content to this matrix and explore how the content we have listed compares with our aims and criteria.

The question of what, in all this, youngsters need to know is not straightforward. Arguably, there are many members of our society who have a minimal understanding of scientific concepts and yet who survive and prosper. Their need to know is not great. On the other hand, society requires that the population has a minimum level of scientific literacy; that people have a basic 'core' of the understandings needed for life in a scientific and technological society.

An article entitled 'Public understanding of science' in *Physics Education* (see Further Reading list) contained suggestions for a core that would include understanding of:

- statistical behaviour (with its applications in risk perception, and therefore nuclear power);
- basic mechanics (with many real-life applications, such as road safety);
- basic thermodynamics (energy conservation, depletion of fuel resources);
- basic systems theory (fallibility of instruments);
- science as a human activity (fallibility of scientists, consensus nature of scientific development).

This list is clearly rooted in physics, and biologists, chemists, earth scientists and technologists would no doubt compile differing lists. Our list, which accommodates as many of these interests as possible, follows in Section 3.

CRITERIA FOR CONTENT

AIMS	must maximise the possibility of teaching the processes, skills and attitudes	must be taught to, and owned by, all pupils	should have some relevance and applicability; must need to be known and be transferable to a range of contexts after school	must appeal to both male and female students, and to students of differing cultures	must be part of a broad and balanced school curriculum	teaching strategies and resources must exist to teach it	must be a basis for further study	must take account of local circumstances
study the key concepts and principles of science as a way of looking at the world								
study those aspects of science that are essential to an understanding of oneself, and of one's personal well being								
study key concepts that are essential to an understanding of the part science and technology play								
study the key areas of science and technology that relate to the world of work and leisure					A			
discuss, reflect upon and evaluate their own personal understanding of key scientific concepts, theories and generalisations								
explore topics and themes which exemplify the limitations of scientific knowledge as an explanation of the human condition								

SECTION THREE

The content list

Areas of study

Over a period of five years between the ages of 11 and 16, students should gain competence in the following areas of study.

Adaptation and evolution

Students should:

- appreciate that all organisms are adapted to their environment to a greater or lesser extent;
- study a number of organisms in their natural surroundings in order to appreciate their adaptations and the ways in which they interact;
- realise that gradual improvements in the adaptations of organisms take place over many generations, and that such improvements are called evolution;
- be aware of some of the major pieces of evidence for the process of evolution.

Biosphere

Students should:

- realise that the biosphere is in a state of dynamic equilibrium;
- appreciate that cyclic transfer of energy and of particles maintains this equilibrium;
- understand and investigate the tenuous hold that the equilibrium has because of human pressure upon it;
- examine cases of its disruption which have short- and long-term effects with severe implications for all living things.

Chemical interactions

Students should:

- be aware that many of the properties and processes in living and non-living things can be explained in terms of interactions between particles;
- not be expected to handle problems involving particles in any quantitative way;
- experience at a laboratory level a range of interactions between important chemical substances;
- investigate the relationships between the speed of such interactions and the chemical and physical state both of the reactants and their environment;
- appreciate the roles of catalysts in living and non-living systems.

Classification

Students should:

- appreciate the normality of the human need to try to impose order on a diverse natural world;
- understand that humans have developed classification systems to answer such needs;
- examine in depth such classical examples of ordering as the Linnaean system and the periodic classification of the elements;
- know how to develop key systems for the identification of individuals within a set;
- be able to use such classification systems for prediction and to alter or replace them in the light of the discovery of exceptions.

Communication

Students should:

- understand that living things communicate in many different ways;
- examine and experience signalling by means of sound, scents and other chemical means, colours and physical contact;
- appreciate the particular subtlety and range of human means of communication such as speech, facial expression, scent and bodily contact and that such attributes arguably distinguish humans from other animals and living things;
- investigate and understand the advances in long distance communication of the past century;
- appreciate the technological progress which such rapid communication implies.

Community

Students should:

- examine and experience some of the multitude of examples of interactions between organisms and populations which give rise to living communities;
- investigate communities in order to establish the relationships between the organisms within them.

Computer systems and microelectronics

Students should:

- appreciate the variety of uses to which computer systems can be put, including:
  the handling and analysis of information;
  the control of electromechanical devices;

- have opportunities to:
  write their own computer programs;
  write scientifically using word-processing systems, thus appreciating their uses and potential; handle and manipulate data using computer database programs;
  use computer-assisted learning programs.

Electricity and electromagnetism

Students should:

- know that two types of electric charge exist; have generated such charges and studied the relationships between them;
- investigate practical applications of, and practical problems caused by, static charges;
- understand the requirement for a circuit to exist before electricity can flow;
- be able to describe electrical observations in terms of the relationships between potential difference, current and resistance;
- appreciate that electric currents also transfer energy which can be transformed by various useful devices into other forms;
- study these phenomena in a laboratory using low-voltage DC supplies and on a microcomputer using simulations to learn how to work safely with their household electricity supply;
- have an understanding of the way in which electrical energy can be generated for practical use and that electricity is produced by all generation schemes which do not use fossil fuels;
- study the implications of the various methods of energy production especially in terms of fossil fuels, pollution and population growth;
- investigate the properties of magnetic substances and of electromagnetism;
- study the interactions of magnetic fields and electric current which produce motion or potential difference.

Energy changes

Students should:

- be able to explain the behaviour of systems in terms of the transfer of energy between their components;
- appreciate the variety of ways (such as temperature, brightness, velocity, height, field strength and strain) by which systems show evidence of their energy content;
- understand the variety of sources by which humans can obtain energy in useful forms, such as the burning of fossil fuels, hydro-electricity, solar, wind and wave power and by nuclear mechanisms;
- spend time listening to public concerns over depletion of fossil fuels and over the production and use of nuclear energy and be able coherently to express the evidence which has led them to form their own opinions on these matters.

Equilibrium, feedback and control

Students should:

- know the attributes of a system in equilibrium and how to recognise such a system;
- study examples of such systems from the biological, chemical, geological, physical and societal worlds;
- be aware of how, in some of the more everyday of these examples, changes in attributes can be used to maintain the equilibrium in the system.

Food chains and webs

Students should:

- study a large number of natural communities chosen according to their own interests and to availability;
- investigate the balance of these communities and the flow of energy and materials within them;
- understand the various ways of representing such relationships by, for example, food chains, webs and pyramids of number or of energy.

Health

Students should:

- understand health as personal well-being which reflects the dynamic continuum of inter-related physical, developmental, social, emotional, economic and political influence on individuals;
- possess the skills which will enable them to understand the dynamics of relationships and interact with others sensitively in order to maximise their own social interactions;
- be able to weigh conflicting evidence about health issues and recognise the political and economic variables which may underline such evidence and its presentation;
- learn to use evidence and information from different sources as an aid to decision making about their own behaviour and lifestyle and that of their own community;
- understand the functioning of their own bodies under different conditions, the probable reasons for the body's tendency to malfunction under the influence of different variables and the true role of experts in the understanding of such malfunctions.

Heredity

Students should:

- study examples of inherited characteristics involving both the plant and the animal worlds;
- develop simple rules which govern the ways in which characteristics are handed down;
- be able to identify biological variation as involving the inheritance of characteristics;
- know that much of the similarity between organisms related by descent is due to their posessing similar inherited material, but that their environment is thought also to affect them;
- appreciate that to elucidate the balance between inherited and environmental effects is very difficult.

Lithosphere and physical landscape

Students should:

- be given opportunities to study in the field and at school the lithosphere, the materials of which it consists and the various processes which characterise it; understand the working of the rock cycle, the effect it has on the appearance and structure of the physical landscape and the importance of its various stages;
- appreciate how the physical landscape and lithosphere can also be affected by such factors as farming, mining and vegetation growth;
- examine these factors in terms of the needs of humans and of the Earth and be capable of forming an opinion on such problems and of justifying it;
- appreciate that the physical landscape and lithosphere are in a state of continuous, extremely slow, movement and change.

Living systems

Students should:

- be able to recognise those characteristics of living systems which distinguish them from the inanimate;
- know that organisms are made up of cells, tissues and organs, the structures of which are matched to the functions they perform;
- understand the necessity for, and the powers of, one system drawn from the plant and one from the animal worlds, selected to bring out comparison and contrast;
- be aware of the capacity for reproduction in living things and their need for such a mechanism;
- understand that respiration is the transfer of energy within all living organisms and is an essential function for life;
- investigate the problems caused by increasing size and variable shape and the mechanisms which organisms have developed in order to solve such problems and so to survive.

Materials

Students should:

- realise how many and varied are the materials which are of use to humans;
- understand the implications of the shortage of some of these important materials or the energy needed for their extraction and/or manufacture, and of the problems caused by their deterioration over time;
- be concerned to know how useful materials may be handled safely, be able to weigh up the considerations of safety and necessity and be willing to come to balanced decisions about continued usage of suspect materials;
- appreciate the extent to which human ingenuity has been harnessed towards the production of many more useful materials and the extent to which these are also problematic.

Matter

Students should:

- appreciate that matter is composed of very small particles, which can be charged or uncharged, and that the arrangement and type of such particles determines both the physical and the chemical properties of materials;
- know that such particles are composed of three smaller types of particle but not be expected to understand the relationships between these smaller particles and the Periodic Table;
- understand that some atoms are unstable and can change into smaller ones by a process known as radioactive decay, emitting one or more of three types of radiation;
- appreciate both the useful applications and the problems of radioactivity.

Models

Students should:

- realise that science has particular ways of working with evidence, theories, hypotheses, models and metaphors;
- be given opportunities to examine evidence and develop and test their own theories, hypotheses, models and metaphors, thus appreciating the strengths and the weaknesses of such approaches;
- study cases from the recorded history of science which reflect these processes and examine the creativity involved in them;
- appreciate how science depends not only on

the ways it uses such ideas but also on the limits it places on their use;
- understand that, although the scientific way of looking at the world has been particularly successful in enabling technological development, it is only one of a number of perspectives and it cannot stand on its own;
- be given opportunities in their own work to combine, compare and contrast the scientific approach with other approaches.

Nutrition

Students should:

- know the constituents of a balanced diet for babies, children, adults and pregnant women and realise its importance in terms of health, growth and energy supply;
- understand that differences in age, physical make-up, ethical viewpoint, cultural or religious background or geography may cause the nature of the balanced dietary intake of individuals to vary;
- have the opportunity to study and respect the reasons for differences in individual diets;
- be concerned for the problems involved in the proper feeding of the world's population;
- have access to reliable data concerning foodstuffs and have the opportunity to decide and justify their own dietary regime.

Photosynthesis

Students should:

- know that organisms containing chlorophyll use the energy of light to synthesise carbohydrates from simple inorganic substances and that oxygen is released as a by-product of the reaction;
- know that cellulose for plant cell walls, proteins for cytoplasm and enzymes, fatty substances for cell membranes and pigments for flower petals are all made by the plant from the products of photosynthesis and other raw materials;
- understand how it is that photosynthesising organisms are the fundamental providers of life for all other organisms;
- be able to identify the producers, primary and secondary consumers and decomposers in an unfamiliar community and to explain the interdependence of these types of organism;
- appreciate the importance to all living things of maintaining the numerical balance between the various types of organism.

Population growth

Students should:

- investigate the growth of populations of various organisms and understand why they have a tendency to grow geometrically in size until limited by one or more environmental resources;
- look especially carefully at the growth of the human population, the reasons for it and the likely consequences if unchecked;
- have opportunities to develop their own thoughts towards this problem and to develop an appreciation of the attitudes taken towards it by people of various political, ethnic, religious or educational backgrounds.

Relationships

Students should:

- appreciate that personal and social relationships are dependent not only on how people perceive themselves, their own self-image, but also on the nature of the groups that they are part of and the dynamics of those groups;
- be practised in the various skills involved in approaching scientific problems as individuals and as members of groups;
- understand the special scientific meaning given to the term 'relationship' as a description of a connection between phenomena;
- be aware of the part which the elucidation of increasingly sophisticated relationships has played in the history of science.

Solar system and Universe

Students should:

- know the composition and arrangement of our solar system in terms of the Sun, planets, asteroid belt and artefacts;
- appreciate that the Sun is a member of a system of stars called the Milky Way galaxy and that this galaxy is but one of millions in an expanding Universe;
- know that the Universe has been the source of many theories throughout history in terms of its origins, size, operations and habitation;
- realise that the study of the heavens was one of the earliest of human scientific activities and achieved great scientific sophistication before any other field;
- be aware of early geocentric theories about the solar system;
- be aware that the shift to the heliocentric model was not accomplished without difficulty and that study of this piece of scientific history can illuminate the interaction between science, politics and belief;
- appreciate the desire which humans strongly possess to explore the heavens and the magnitude of the achievement thus far and the

benefits for the citizens of Earth;
- discuss the balance of risk, expense and possible benefits of space programmes and be able to justify their attitude towards them.

Technology

Students should:

- have opportunities to work across the interface between science and technology;
- understand the effect each has on the social, economic and political status of society in such areas as environmental quality, food, materials resources, health, communication, automation, biotechnology, transport, leisure, survival and war;
- be practised at the attempted solution of a range of self-defined and open-ended scientific and technological problems and be prepared to tackle others of this sort defined not by themselves.

Weather

Students should:

- be able to explain the weather in general terms of large-scale movements of atmospheric air masses;
- be aware of the significance of the measurements which can now be taken of air pressure, temperature, humidity, rainfall, wind speed, wind direction and cloud cover in terms of their effects on farming, vegetation and soil type and human activity.
- understand the broader effects that climate has on the nature of plant and animal communities;
- analyse collected data and attempt to make forecasts based on them and on data garnered from other sources;
- realise the variable accuracy of weather prediction and the reasons for it and the great contributions which satellites, large computers and human intuition and experience make to this field.

Processes, skills and attitudes

Only some of the many desirable processes, skills and attitudes may be apparent in this list. We give these here separately for the sake of emphasis. Some are general to many subject areas – are general education processes and skills. Some are more specifically scientific.

For a more discursive description of some of the lists see *Towards the Specification of Minimum Entitlement: Brenda and friends* (**1.5**). For a more contextualised description, including discussion of appropriate teaching approaches, see the Curriculum Guide, **Better Science: Approaches to teaching and learning** in this series.

We too see processes to be rational activities involving a range of skills, and these skills to be specific activities which a youngster can be trained to do. Some detailed examples of processes have been well documented (**3.1**).

Processes

Many items in this list concern general educational processes such as:

- Communicating and discussing, which includes:
  questioning; thinking; seeking help; negotiating.
- Processing of information, which includes:
  selecting; using relationships; designing; drawing conclusions; controlling interacting variables.
- Problem solving, experimentation and decision making, which include:
  predicting; inferring; interpreting; formulating hypotheses; modelling; evaluating; assessing; classifying; managing time; costing.

Skills

This list also includes some very general skills:

listening; talking; reading; drawing; numeracy; small group skills; observing; non-verbal communication; searching; measuring; manipulation; graphicacy; recording.

Attitudes

The following are examples of desirable attitudes:

open-mindedness; self-criticism; responsibility; independence of thought; perseverence; cooperation; scepticism; desire to be well informed; confidence; respect; sensitivity; willingness to be involved; enthusiasm; tolerance; persuasiveness; questioning; trust.

Why these items?

We suggested earlier that our content of concepts, skills, processes and attitudes is an attempt to satisfy both our aims and our criteria. To answer the question of why we choose these items we must return to our matrix and explore further the cells there.

One aim is that students should have an opportunity to study the key concepts of science. Our 26 listed topics can be seen to include some of the 'big ideas' of science. For example, we would consider some of the key concepts in science to include:

chemical interaction; adaptation and evolution; community; classification; energy change; electricity and electromagnetism; heredity; equilibrium, feedback and control; living systems; materials; matter; motion; photosynthesis; solar system and Universe.

Another aim would highlight technological issues, for instance:

biosphere; communication; computer system and microelectronics; equilibrium, feedback and control; energy changes; electricity and electromagnetism; food chains and webs; health; living systems; materials; motion; population growth; technology; relationships; weather.

As a further example, it is a prerequisite to the understanding of one's personal well-being to study the following:

communication; community; food chains and webs; equilibrium, feedback and control; health; heredity; living systems; nutrition; population growth; relationships; weather.

Subjects which can be used to exemplify the limitations of scientific knowledge might be:

biosphere; adaptation and evolution; community; classification; communication; electricity and electromagnetism; heredity; equilibrium, feedback and control; food chains and webs; lithosphere and physical landscape; living systems; materials; models; nutrition; photosynthesis; population growth; technology; relationships; weather; solar system and Universe.

We shall attempt to show in the examples of Section 4 how some of the processes, skills and attitudes might be developed from the study of the above topics. First we shall consider other lists of content that have been produced.

Other lists of content

Unfortunately, many of the lists produced by other groups are as long as this Guide and so cannot be reproduced alongside ours for direct comparison. In some ways a direct comparison is not very helpful — not all other lists have taken the same definition of the term content, for instance.

Many of the SSCR working groups, however, have provided brief lists of appropriate content and in the Appendix we give an example of some aspects of the work of a Humberside group, entitled 'A coordinated science programme'. Their work results in what they call a 'hierarchy of mutually interdependent concepts in science learning processes, years 1–5'.

A good description of skills and processes, on the other hand, can be found in the work of the Avon group, *Science for Half Our Children*. They list seven major skill areas such as manipulative, observational, communication, measurement, experimental, social and study.

Why these processes, skills and attitudes?

The items on our lists represent many general educational processes, skills and attitudes. We are not the first, of course, to emphasise processes, skills and attitudes. The DES policy statement (**1.2**) says, for example:

The essential characteristic of education in science is that it introduces pupils to the methods of science. So that scientific competence can be developed to the full the courses provided should therefore give pupils at all stages appropriate opportunities to:

- *make observations;*
- *select observations relevant to their investigations for further study;*
- *seek and identify patterns and relate these to patterns perceived earlier;*
- *suggest and evaluate explanations of the patterns;*
- *design and carry out experiments, including appropriate forms of measurement, to test suggested explanations for the patterns of observations;*
- *communicate (verbally, mathematically and graphically) and interpret written and other material;*
- *handle equipment safely and effectively;*
- *use their knowledge in conducting investigations;*
- *bring their knowledge to bear in attempting to solve technological problems.*

Science education should at the same time give opportunities, through practical work and otherwise, for the acquisition of knowledge and understanding. Just what knowledge of facts and principles should be taught is a matter for continual review, in the light of changes and development in science and technology in the wider world.

The APU, too, has given its lists (**1.10**). A useful discussion of pertinent attitudes can be found in *Teaching and Learning Primary Science* by Wynne Harlen (**2.5**). (see Fig. 1, p. 9).

Another list that indicates the processes, skills and attitudes associated with scientific and technological problem solving can be found in *Problem-solving: Science and technology in primary schools* (**3.2**). These lists are not intended to be exhaustive; they are often generalised lists as writers attempt to summarise skills, processes and attitudes in broad terms.

SECTION FOUR

Examples

In the first part of this section we treat in detail two of the topics from our list in Section 3. In the second part we consider some of the implications of what has been said in the booklet.

As examples we have taken, 'electricity' and 'relationships'. Electricity is a topic that is conventionally part of all science courses in school; the same cannot be said for 'relationships'.

These examples are not intended to be prescriptive but illustrative. The two are very different. Electricity is a fairly traditional part of science; 'relationships' is an unusual heading. Electricity is a topic that can be approached in blocks of time, while relationships is something that might be a continuing thread throughout five years of science. Finally, electricity is often seen as 'girl-unfriendly' while relationships might have greater 'girl-appeal'.

Electricity

Our list in Section 3 had this to say about electricity:

Students should:

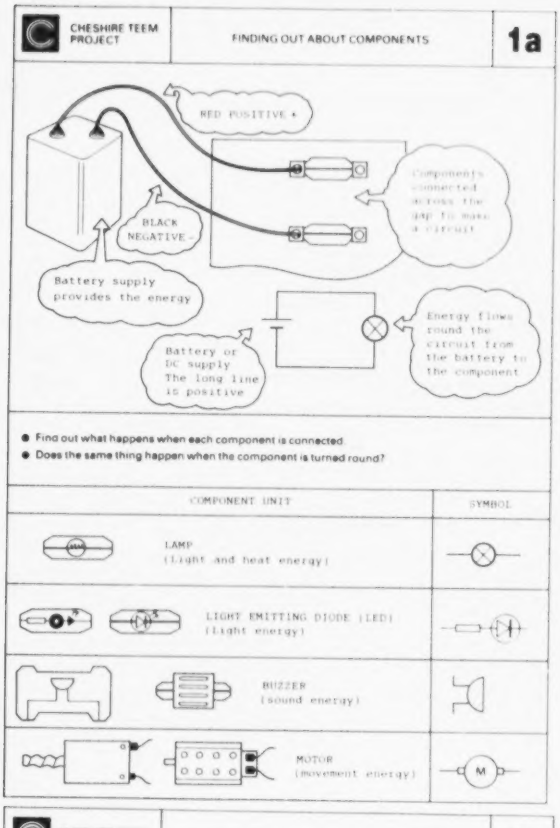
- know that two types of electric charge exist;
- have generated such charges and studied the relationships between them;
- investigate practical applications of, and practical problems caused by, static charges;
- understand the requirement for a circuit to exist before electricity can flow;
- be able to describe electrical observations in terms of the relationships between potential difference, current and resistance;
- appreciate that electric currents also transfer energy which can be transformed by various useful devices into other forms;
- study these phenomena in a laboratory using low-voltage DC supplies and on a microcomputer using simulations to learn how to work safely with their household electricity supply;
- have an understanding of the way in which electrical energy can be generated for practical use, and that electricity is produced by all energy generation schemes which do not use fossil fuels;
- have studied the implications of the various methods, especially in terms of fossil fuels, pollution and population growth;
- investigate the properties of magnetic substances and of electromagnetism;
- study the interactions of magnetic fields and electric currents which produce motion or potential difference.

A scheme of work for electricity might be undertaken in two blocks of time in a five-year period. For example, a course might be organised that explored some early circuit work in year 2 or 3 followed, perhaps, by a term's work in year 4. The early work might deal with basic circuits in a manner similar to that of SSCR working groups in Cheshire (*Technology through Electricity, Electronics and Microelectronics*) or Gloucestershire (*Girls and Science*) where simple circuits are explored using Locktronic® systems of components, or other available materials. Examples of both groups' work are shown in Fig. 3 and Fig. 4.

It is important that time is spent allowing youngsters to develop necessary electrical relationships and familiarity with simple circuits. Some contrasts like 'electrical conductor/non-conductor'; 'static electricity/current electricity'; 'magnetic/non-magnetic' can be explored. It is an opportunity to allow youngsters to explore their own conceptions of electricity. Some examples of typical conceptions of electricity are given in *Learning, doing and understanding in science* (**2.1**), *Learning in Science* (**4.1**), *Children's Ideas in Science* (**4.2**).

Work might also include some of the 'girl-friendly' aspects of the Avon group, *Girls and Science*, for example *The Ampville Horror* role-play activity. Some of the material for this role situation is given in Box 7. Three groups – Planners, an Action Committee and a Panel of Councillors – debate the construction of overhead power lines across their village. This kind of approach allows youngsters to discuss the social implications of electricity, and teachers to provide some variety of teaching methods.

The fourth-year work might have a central core of work leading to youngsters developing their own projects or choosing one of a range of modules, say, in the second part of the term. Some modules might be chosen that allow study of the more sophisticated or quantitative aspects of electricity. The initial section would revisit the earlier work on circuits, draw upon further relationships in terms of current, potential difference and power, and develop measurement skills such as scale reading. It might also include some discussion of some of the historically important personalities in electrical theory, or provide opportunity for market research which is also indicated in the Avon group's material.


CHESHIRE TEEM PROJECT
FINDING OUT ABOUT COMPONENTS
1a
RED POSITIVE +
BLACK NEGATIVE -
Components connected across the gap to make a circuit
Battery supply provides the energy
Energy flows round the circuit from the battery to the component
Battery or DC supply The long line is positive
• Find out what happens when each component is connected
• Does the same thing happen when the component is turned round?
COMPONENT UNIT
SYMBOL
LAMP (light and heat energy)
LIGHT EMITTING DIODE (LED) (light energy)
BUZZER (sound energy)
MOTOR (movement energy)
M
CHESHIRE TEEM PROJECT
MEASURING ELECTRIC CURRENT
1b
A
BATTERY or POWER SUPPLY
• Measure the electric current drawn by each component
A
REMOVE A CONNECTOR SO THAT THERE IS A GAP IN THE CIRCUIT
DIVERT THE CURRENT THROUGH THE AMMETER
PUT THE CONNECTOR BACK IN
A
• Measure the electric current in a different part of the circuit

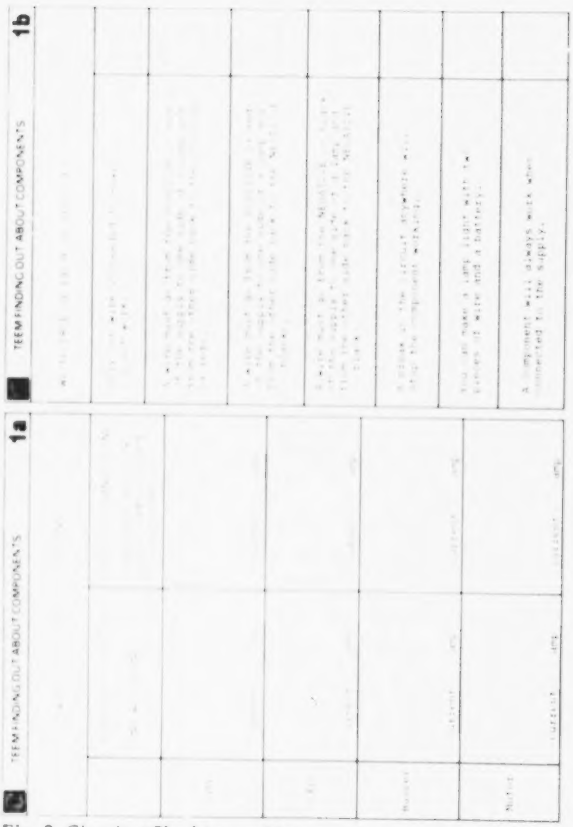


Fig. 3 Circuits (Cheshire working group)

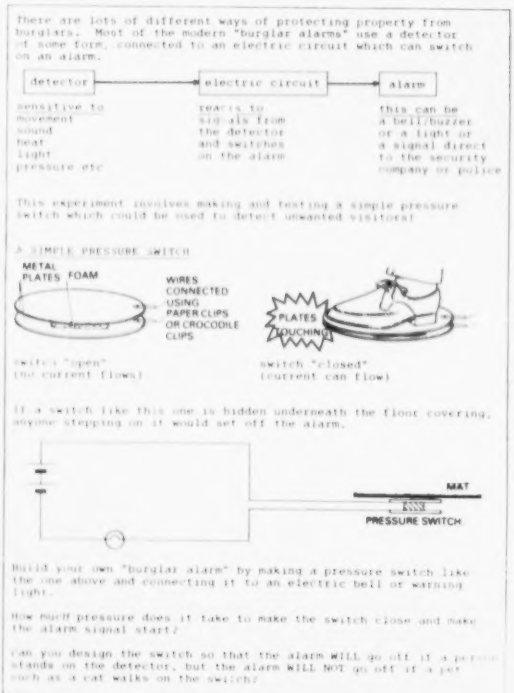

There are lots of different ways of protecting property from burglars. Most of the modern "burglar alarms" use a detector of some form, connected to an electric circuit which can switch on an alarm.
detector
electric circuit
alarm
sensitive to movement sound heat light pressure etc
reacts to signals from the detector and switches on the alarm
this can be a bell/buzzer or a light or a signal direct to the security company or police
This experiment involves making and testing a simple pressure switch which could be used to detect unwanted visitors!
A SIMPLE PRESSURE SWITCH
METAL PLATES
FOAM
WIRES CONNECTED USING PAPER CLIPS OR CROCODILE CLIPS
PLATES TOUCHING
switch "open" (no current flows)
switch "closed" (current can flow)
If a switch like this one is hidden underneath the floor covering, anyone stepping on it would set off the alarm.
MAT
PRESSURE SWITCH
Build your own "burglar alarm" by making a pressure switch like the one above and connecting it to an electric bell or warning light.
How much pressure does it take to make the switch close and make the alarm signal start?
Can you design the switch so that the alarm WILL go off if a person stands on the detector, but the alarm WILL NOT go off if a pet such as a cat walks on the switch?

Fig. 4 Circuits (Gloucestershire working group)

BEST COPY AVAILABLE

Alternatively, sections on electricity might be tacked through problem solving, as suggested in the fourth-year physics work of Suffolk's *The Coordinated Science Project* (**2.4**). The relevance of electricity can be seen in the work of the Gloucester group and Hillingdon's *A Core and Options Approach* (**4.3**). The first considers domestic appliances and their electrical safety; in parts of the second electricity is compared to other forms of fuel and domestic energy losses and the properties of thermal insulation are considered.

The Ampville Horror
Role play/simulation of a Public Meeting

Fact Sheet

The Planners

- Evidence of depression and suicides

The link between suicides and depression and living close to power lines cannot be proven. There may be many other reasons such as social conditions, e.g. a poor standard of living or unemployment, that are responsible.

There is no way of proving that these people would not have felt unwell if the power lines had not been there.

- Other countries

Very few countries have any policy about power lines. The majority do not consider them to present any danger.

- Power workers

There are many hazards in industry, the main hazard being the materials used. So if there is any evidence of an increased risk of cancer, what evidence is there to show that it is because of the electromagnetic field?

- Laboratory experiments

Laboratory experiments are carried out in unnatural conditions. The effect on mice could have been due to other conditions in which the animals were kept.

Isolated cells may behave differently than when in a living body, therefore evidence of damaging effects on cells is worthless.

The body does rely on electrical signals, but the earth itself has a very large electromagnetic field (birds use it to navigate) which does not appear to do us any harm.

Summary

Make your own summary, using the arguments above to conclude that the National Grid has existed for 50 years and covers thousands of miles – all that the objectors can come up with is a few cases of depression. There is NO evidence that power lines are a health risk and the building should go ahead.

Continued in next column

Fact Sheet

The Action Committee

- Evidence of depression and suicide

Fishpond, a village in Dorset, had a 400,000 Volt power line erected across it in the late 1970s. Since then three-quarters of the population have been complaining of ill health, such as tiredness, depression, headaches and heart trouble.

In the West Midlands, Dr. Stephen Perry has found a link between suicides and people living close to power lines.

Wrexham Avenue, Walsall, contains 78 houses. In the past 13 years, four residents have committed suicide. The odds against this are 5,000 to 1.

- Other countries

In some countries (e.g. USSR) and some states in the USA it is illegal for power companies to place power lines too close to houses.

- Power workers

There is scientific evidence to show that there is twice the chance of power workers suffering from cancer.

- Laboratory Experiments

When exposed to electromagnetic radiation, experiments with mice showed that after three generations the growth of the mice became stunted.

Dr. David Melville, a physicist at Southampton University, has shown that magnetic fields affect 'nature's buildings blocks – cells'.

Professor Robert Becker, an American surgeon, explains that our bodies rely on tiny electrical signals to work properly and it is, therefore, not surprising that people exposed to abnormal electromagnetic fields suffer from health problems.

Summary

Make your own summary, using the weight of the scientific evidence above to conclude that while there is ANY possibility that power lines are a health risk, the building should not go ahead at the site put forward by the planners.

Continued on next page

Role Card

The Panel

- You must elect a chairperson.
- You may like to appoint a person (or two) to take notes.
- Listen carefully to both sides.
- Ask questions.
- When both sides have put their cases, you must discuss the information amongst yourselves.
- Make a decision. You can decide to:
  - allow the building to go ahead as planned
  - put a stop to the building completely
  - tell the planners to find a new site
- The decision is announced by the chairperson, who must also explain the reasons for the decision.

Role Card

The Action Committee

Your main task is to persuade the panel that the building should not go ahead if there is any possibility that the power lines present a possible health risk.

The school and some of the houses must not be built under the power lines, but should be moved to another site in another part of the town.

The main points of your argument are:

- Illness/suicide amongst people living close to power lines.
- Policies in other countries
- Case studies on the health of power workers
- Laboratory experiments on mice and cells
- 'Scientific evidence' shows that there are risks

Further details of these points are given on your FACT SHEET.

***Box 7** 'The Ampville Horror' role play (Avon working group)*

Relationships

In the list in Section 3 we had this to say about relationships:

Students should:

- appreciate that personal and social relationships are dependent not only on how people perceive themselves, their own self-image, but also on the nature of the groups that they are part of and the dynamics of those groups;
- be practised in the various skills involved in approaching scientific problems as individuals and as members of groups;
- understand the special scientific meaning given to the term 'relationship' as a description of a connection between phenomena;
- be aware of the part which the elucidation of increasingly sophisticated relationships has played in the history of science.

Although science is littered with relationships of many sorts, it is not common for school science to focus upon relationships as such. Exceptions might be those courses which consider patterns, for example, a term we subsume here within relationships. A working definition for relationships might be the different kinds of connection, correspondence or contrast between persons or things. From this definition it can be seen that different aspects of relationships come into many areas of science.

There is a strong sense in which it might be thought that the term is ambiguous – that it has two distinctive meanings. For instance, it might be said that Hooke's law and Ohm's law describe particular types of relationship very different in kind to human and personal relationships. In our description of the term we force no such distinction. Just as there are connections between the acceleration of an object and the net forces applied to it, so there are connections between sunlight and marine life, self-discipline and laboratory safety, human diet and social culture, the siting of nuclear power stations and economics, personal development and sex education, and so on. Just as there are contrasts to be explored between chemical and physical changes, metals and non-metals, magnetic and non-magnetic materials, so there are contrasts to be drawn between dissection and vivisection, fish farming and angling, sympathy and empathy, future employment possibilities with a science qualification and without one, and so on – all of which, we would argue, fall within the remit of science education.

We are not suggesting that these connections should be the sole domain of science teachers but that they, too, have a role to play in the education of youngsters regarding such issues. Needless to say, some of the relationships mentioned are quantifiable, mathematical ones, while others are not. The relationship between the activity of a radioactive substance and time is quantifiable, whilst the location of a nuclear power station in relation to the economics of national electricity supply is probably not. Nevertheless, school science is concerned not just with mathematical relationships but a good deal else besides, which we hope is illustrated here.

We have drawn our 'Relationships' plan in two ways: first, as a theme which runs through all parts of science, as a process of raising awareness; secondly as a specific area to be taught, so that youngsters begin to organise their experiences in sciences in a way that allows them to practise some of the processes and skills above. The 'Relationships' content provides an opportunity,

for example, to examine notions – and limits – of causality. We have called this 'appreciating connections'.

Raising awareness

We see the exposition of the contrasts and connections between things as a continuous process in the teaching of 'Relationships' and one that is applicable to the teaching of other topics. It is not easy to be specific about what might be included within such an 'awareness-raising' scheme, since much of it will depend upon the themes and aspects being explored at any one time. Let us, however, concentrate on two major aspects. The first is human and personal relationships, since we feel this is an underexplored area in science. The second is to view a common science topic through the framework of relationships. We have not, for the most part, designated any specific ages at which we feel such issues to be important. Instead, we make the assumption that the scheme continues throughout a young person's school science career.

Personal relationships

The output of a Devon SSCR working group, *A Skills Approach to the Teaching of Science in the Lower School: Listening* (**4.4**) provides a good start. The group has produced work on science skills, in particular a unit of resources for teachers on listening skills. Its approach is to provide a series of exercises which focuses youngsters' attention in class on aspects of listening as both a form of observation and a major feature of human relationships. For instance: what interferes with listening, what enhances it, how do you know when you are doing it, how do you know when others are doing it? The approach assumes that short five- or ten-minute exercises might take place periodically alongside other science work so that young people are continually reminded of the notion that listening skills are an important part of any relationship between people when ideas are being shared. Careful listening highlights how decisions are reached, how cooperation proceeds in managing and conducting relationships (for example in negotiation, assertion, aggression and status). It can highlight, too, group dynamics (for example, listening to several others, the development of leadership, the roles of participants, issues of trust). These can be an excellent way for young people to practise their observational skills. As the Devon group suggest, a scheme of awareness raising is something that continues over the five years of secondary school life. The management of relationships is one returned to, for short periods of time, on a regular basis during science lessons. For example, during a science lesson on population (or indeed any other science topic where young people work in groups and engage in cooperative activities) one member of each group can be given the task of observing the interactions in the group. Who takes the lead, what changes the course of discussion, who talks and who remains silent? (Is it the boys who dominate discussion, for example?) How are decisions reached?

We would call this keeping a dynamic diary. Over a period of a fortnight or so, all the youngsters in the group play 'dynamic observer'. One lesson might then be given over to a discussion of the observations, and youngsters be invited to generate, and test, hypotheses about the dynamics of the groups.

In other words, young people are asked to focus attention on aspects of human interaction within the context of their own working groups, share observations on how they see others cooperating, leading, opting out or organising work, in an effort to examine some of the underlying issues in working in teams and as individuals.

Another Review group from Manchester has worked in this area; the group has produced a series of half-termly modules, *Psychology in School Science*, which focus upon issues such as 'learning and problem solving', 'leadership' and 'persuasion'. These are specific units of work which emphasise a practical approach to social psychology using scientific methods. These units also raise questions about the appropriateness of using particular scientific methods when discussing relationships between people and their environments.

The framework of relationships

A Sheffield group has produced some excellent work for youngsters on biotechnology (*Biotech;* **4.5**). Its work includes making yoghurt, examining washing powders and considering aspects of genetic engineering and cell cloning. During the work on yoghurt making, for example, teachers can draw attention to the connections between temperature and bacterial growth. In the section of genetic engineering there are opportunities to explore the relationship between insulin and blood sugar level, or to focus on analytic skills by exploring possible causal links between the increased incidence of diabetes and the high sugar content of western diets.

There are many other such examples. The important point is that young people are continually cautioned to analyse the 'connectedness' between things, and are asked to be critical in their estimations of connectedness.

Appreciating connections

It is important, too, at various points, to consolidate some relationships in science. Young

people should be asked to work on relationships specifically as an issue. Examples might come from the units of the Manchester group mentioned earlier. Other Review groups who have focussed upon such aspects of science are:

- From Newcastle: *Man and the Environment*. Relationships of people with the environment in which we live.
- From Hertfordshire: *An Approach to Health Education for Science Teachers* (**4.6**). Relationships with people in the family on such issues as death and feelings about death.
- From Kent: *Geoffrey Chaucer Health Education Teams*, a module of work on relationships in sex education.

In this way we would see the issue of causality being examined in detail, along with the estimation of quantification of 'connectedness', the exploration of the theories young people have been developing from their dynamic diary observations and the application of all this to the real world in which scientists work in research teams to bring ideas to fruition.

SECTION FIVE

Implications: final comments

This guide is not a report but a discussion document. Our intention has been to focus discussion and debate upon shaping the content of science education, and to introduce some of the work of SSCR working groups. There remain some final points that deserve comment. Here we note some implications of what has been said.

Resources

Discussions of the resources implications of change are always complex: there is no simple way in which the resource requirements for changes in content can be calculated for all schools in all circumstances. Moreover, resources themselves are not always easily calculable. They often include teacher time and energy, technical assistance, buildings, room design, furniture and services, hardware and equipment, consumable items or transport facilities. There might well be the need for additional resources, for example, where a school moves towards a more process-based course, or where new materials and texts are thought more appropriate.

Resources are discussed more fully in the Curriculum Guide, **Better Science: Key proposals** and in **Better Science: Making it happen**.

Further study

We suggested earlier in our criteria for inclusion of content that science education between 11 and 16 should provide a basis for further study. For us, content has two requirements. First, the content of science education must allow all youngsters some access to the world of science so that they can continue studies at a variety of different levels – whether for vocation or for leisure. Secondly, it must allow access to A-level study.

Throughout this booklet we have avoided being prescriptive about how or when particular aspects of science should be taught. Our list of content is a checklist against which schools can compare their current provision. It is a suggestion to take into account the broad aims of science education and the needs of a wide constituency of 'users'. Importantly, it is a list that stretches over five years of education and is not a two-year examination syllabus. The content we list can be tackled in a variety of ways and there are numerous examples of Modes 1, 2 and 3 examination syllabuses within the work of SSCR groups illustrating how they have attempted some of this work in years 4 and 5.

With the onset of the General Certificate of Secondary Education it is difficult to predict the range and variety of examination provision that will allow further extended study. We can, however, check that the elements of science we have suggested are not incompatible with the needs of those who would continue science to A level. In a recent article Blin-Stoyle **(5.1)** suggests that a nationally agreed core of content can be identified that will flow from work between 11 and 16 through to A level and undergraduate studies. For example, he commends the physics core prepared by the Institute of Physics **(5.2)** which we in turn have used as a guide in considering our content list in Section 3. If, as Blin-Stoyle suggests, there is the time and opportunity for youngsters to understand thoroughly and confidently the core elements of science, such cores can be explored and developed to individuals' needs both within the time allocation for science to 16+ and at A level.

We are confident that our list contains within it the elements of a broad and balanced science curriculum that will provide the springboard for competence at 16+ and will act as a vehicle for further and higher study.

APPENDIX

Part of the work of a Humberside group: a *Coordinated Science Programme*

A hierarchy of the mutually interdependent concepts in science learning processes, years 1–5

The following table represents our judgements regarding the sequencing of those concepts which are *mutually interdependent*. This information is *not* intended, therefore, to represent the total content of the relevant syllabuses but rather deals only with those areas in which there is seen to be some degree of interaction. The content thus becomes increasingly sparse towards the end of year 5 since the increasing level of subject specialisation appears, at this level, to reduce the degree of dependence of one subject upon another. However, the converse is true in the lower age groups, and here it is considered to be particularly vital to take note of interdisciplinary dependence.

Table I identifies the concepts associated with each subject area and gives sufficient expansion to identify the limits of the 'sub-concepts' within each concept set.

The 'level' at which each concept is introduced should be taken as expressing relationship with, or dependence on, the content of earlier concept levels, and is not meant to equate with particular terms or years of the courses. However, it is apparent that concept hierarchy sequencing should be reflected in the pattern of science curriculum development from term to term and from year to year. A boundary has also been drawn in to indicate the approximate concept levels that we would expect an average pupil to achieve by the end of the foundation courses of years 1 and 2, and also at the interface between years 3 and 4 to indicate the concept levels which we feel it is appropriate for an average pupil to have achieved before starting the more specialist components of the exam courses in years 4 and 5.

Discussion with colleagues in maths departments has also brought to light the serious discrepancy not only in processes but also in concepts between content and timing of the various maths and science courses. Some provision needs to be made for the linking together of the teaching syllabuses in these areas so that they become mutually complementary and reinforcing. Science courses demand an understanding of, and ability to manipulate, ratios at many points throughout years 1–5, but invariably well before the stage at which maths colleagues feel that pupils are able to understand and use this concept. Pupils brought up on SMP maths are especially prone to disaster in this area.

May we, therefore, make an urgent plea for coordination of maths and science syllabuses.

Within the sciences it is also apparent that there is need for agreement on the use of symbols, abbreviations and other forms of scientific 'shorthand'. Particularly, there needs to be agreement on the point at which these are introduced in the various syllabuses. The use of chemical formulae was seen as a case in point by many of the local working group members. Chemists generally felt that the concepts that they wished to be taught by means of introducing chemical formulae were undermined by the prior, 'loose' introduction, particularly in lower school science courses and in their quite excessive use at all levels in general biology courses.

Our chemists generally felt that although chemical symbols could be introduced early on in science (year 2), the use of chemical formulae could not be made meaningful until the year 3/4 boundary had been reached. Other science teachers may feel differently on this issue but nevertheless we should like to urge further consideration based on concept hierarchies rather than on tradition!

From Table I, level 9, it may be seen that there is considerable interaction at this point between all three sciences and particularly between biology and chemistry. Close cooperation between chemists and biologists at this point should be particularly valuable both in preventing unnecessary overlap and in ensuring the best possible sequence of presentation for pupil understanding.

TABLE I: Suggested concept hierarchy

Level	Biology	Chemistry	Physics	Major theme
1	Variability of living things; classification; characteristics of 'life'; cells as basic 'life units'.	Variability of chemical substances; classification; separation.	Variability of dimensions; measurement and scales; estimation and accuracy.	*Variability* *Classification*
2	Growth; reproduction (life cycles); populations.	Concentration (qualitative); physical change; chemical change	Forces: I. (types, effects and measurement)	*Change*
3	Interactions between organisms; (habitats, soils, simple microbiology).	'Burning' (Combustion, fuels and elementary Redox)	Simple magnetism; electrostatic charge (+ve, −ve)	*Interactions I*
4	Interactions inside organisms: I. (cells, tissues and organs of mammals and flowering plants).	Air and oxygen	Energy: I. (forms and transfer, observation and labelling)	*Interactions II*
5	Food as 'fuel'; feeding; simple food chains.	Electrolysis: I. chemical effect of electric current.	Electricity: I. (conductors and insulators, current and measurement, voltage and measurement)	*Energy flow and transfer*
Prospective year 2/3 boundary				
6	Interactions inside organisms: II. (organ systems, food, diet, the gut); health	Conservation of chemical identity; (element, compound, synthesis, decomposition, catalysis).	Matter, its nature and states; density; diffusion.	*Matter*
7	Surface area: volume; exchange between the organism and its environment. (Respiration I, Photosynthesis I, Digestion I.)	Synthesis of oxides; reaction speeds; Redox and reactivity.	Heat transfer. Light: I. (rays, spectrum) Sound: I (wave propagation)	*Reactions and energy flow*
8	Reproduction II (human, flower).	Structures and forces (atoms, molecules, ions, acid, base, salt. crystals); periodic table.	Electromagnetism; motion (speed, velocity, acceleration).	*Structures and patterns*

Continued on next page

Level	Biology	Chemistry	Physics	Major theme
Prospective year 3/4 boundary				
9	Metabolism (cells as chemical systems); respiration: II. photosynthesis: II. digestion: II. (enzymes); excretion; food and energy. (It would seem particularly important to have close cooperation between the three disciplines at this stage in order to promote summative interactions.)	Bonding and the 'Rutherford atom' (electron shells, sharing and transfer of electrons); Organic chemistry: I.	Energy: II. (changes, conservation); work, joules, power, watts. Forces: II. (*f=ma*: momentum impulse, weight/ gravity/action at a distance). Hooke's law; moment of force; static pressure.	
10	Coordination; communication; behaviour.	The mole (as amount of a substance); Redox (as gain/loss of electrons).	Electricity: II. (current as rate of flow of charge). p.d., Ohm's law, resistance; parallel/series resistors; electrical energy; electrical power.	
11	Ecology; conservation; biotechnology. Osmosis; transpiration.	Electrolysis: II. (electrode processes). Equilibrium (forward and reverse reactions); effect of concentration on rate and equilibrium position.	Heat: II. (heat capacity, specific heat capacity, exothermic and endothermic reactions; cooling curves, latent heat).	
12	*Simple* inheritance; genetic 'illness'.		Light: II. (light as wave motion); Electromagnetism: II. (transformers, generators and power transmission).	
	(Throughout all these concepts it has been assumed that presentation will, wherever possible, include social implications and industrial/domestic applications and processes.)		Energy: III. (nuclear energy and radioactivity). Electronics and microelectronics.	

(a) Throughout sections 1–5 it is assumed that concepts will be experienced qualitatively and thus in a largely non-mathematical way. Sections 6–8 should see the gradual introduction of quantitative approaches with an increasing use of mathematical skills.

(b) It has been stressed in the text that this is not intended as a complete syllabus outline. However, in the construction of syllabuses, it is our contention that each level is more or less dependent on the content of preceding levels, possibly in all the subject disciplines. It is therefore important to construct both syllabuses *and teaching schemes* in the light of this sequence.

Further reading

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Eisner, E. *Cognition and Curriculum*, Longman, 1984.

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The Secondary Science Curriculum Review (SSCR) was set up in 1981 to stimulate, through working groups of practising teachers, the development of science studies which would help to provide an appropriate science education for *all* young people growing up in a scientific and technological society — whatever their abilities or career intentions. Its concern was not only with the science curriculum — its contents, purposes, teaching methods and resources — but also with the role of science in general education and within the whole school.

The **Better Science: Curriculum Guides** are based on the combined experience of the Review's Central Team and the working groups. Each Guide deals with a different but significant area of concern. Together they aim to assist teachers both in devising a broader and more balanced approach to science studies and in enhancing their professional development. The intention throughout is not necessarily to provide answers but rather to provoke and encourage teachers' thinking about the various topics addressed.

This Guide, **Better Science: Choosing content,**

- considers many of the claims made on science courses;
- offers some examples and solutions to the calls for 'broad, balanced science for all' and 'process not product';
- aims to assist in the task of deciding *what* to teach in school science.

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